

**STRUCTURAL EQUATION MODELLING AND SYSTEM DYNAMIC IN THE  
DETECTION OF POWER QUALITY EVENTS**

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For my beloved father, mother, sisters and brothers.



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## ABSTRACT

The issues of power quality had been discussed since the starting of power system and it will keep on arise from time to time because power quality is important to electricity consumers at all levels of usage. Since sensitive equipments and power electronic devices are now more common in industrial/commercial sectors as well as domestic use, the awareness of power quality is developing amongst electricity users. In general, the main power quality issues can be identified as voltage variations, voltage imbalance, voltage fluctuations, transients, harmonic distortions, interruptions, etc. The consequences of one or more of the above non-ideal conditions may cause thermal effects, life expectancy reduction, dielectric strength reduction and disoperation of different equipments. In this project, power quality events are verified using Structural Equation Modeling (SEM) and System Dynamic method. In detecting power quality events, Amos 5.0.1 and Vensim PLE for Windows version 5.11 were used. The verification of power quality events involves identification, classification and mitigation process on several power quality events that occurred in electrical power system.

## ABSTRAK

Isu-isu tentang kualiti kuasa telah dibincangkan semenjak bermulanya sistem kuasa dan ia akan terus dibangkitkan dari masa ke semasa kerana kualiti kuasa adalah penting kepada pengguna-pengguna bekalan elektrik pada semua tahap penggunaan. Disebabkan peralatan-peralatan sensitif dan juga peralatan elektronik kuasa semakin biasa digunakan di dalam sektor industri atau komersial serta kegunaan domestik, kesedaran tentang kualiti kuasa berkembang di kalangan pengguna-pengguna bekalan elektrik. Secara amnya, isu utama kualiti kuasa boleh dikenalpasti melalui variasi voltan, ketidakseimbangan voltan, naik-turun voltan, transien, pengherotan harmoni, gangguan dan sebagainya. Akibat daripada satu atau lebih daripada keadaan-keadaan tidak ideal seperti yang di atas boleh menyebabkan kesan terma atau kepanasan, pengurangan jangka hayat, pengurangan kekuatan dielektrik dan ketidakfungsian peralatan. Di dalam projek ini, gangguan kualiti kuasa disahkan menggunakan kaedah *Structural Equation Modeling (SEM)* dan *System Dynamic*. Dalam mengesan gangguan kualiti kuasa, perisian AMOS 5.0.1 dan Vensim PLE for Windows Version 5.11 digunakan. Pengesanan gangguan kualiti kuasa melibatkan proses mengenalpastian, pengelasan dan penyelesaian kepada beberapa gangguan kualiti kuasa yang berlaku di dalam sistem kuasa elektrik.

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## LIST OF ABBREVIATIONS

LISREL	-	Linear Structural Relations
SEM	-	Structural Equation Modeling
RL	-	Resistor-Inductor
ADALINE	-	Adaptive Linear Neuron
DC	-	Direct Current
CBEMA	-	Computer Business Equipment Manufacturing Association
ANSI	-	American National Standards Institute
ITIC	-	Information Technology Industry Council
PQ	-	Power Quality
TNB	-	Tenaga Nasional Berhad
RPM	-	Reliable Power Meter
THD	-	Total Harmonic Distortion
RMS	-	Root Mean Square

## CHAPTER 1

### INTRODUCTION

#### 1.1 Project Introduction

Structural equation modeling is an extension of the general linear model that enables researchers to fit more than one regression equation simultaneously [1]. It encompasses a larger number of statistical procedures including latent variable analysis, confirmatory factor analysis, causal modeling, LISREL analysis, growth curve modeling, etc. Structural equation modeling possess several advantages which includes the incorporation of latent variables can significantly reduce measurement error. In other words, the more indicators you have for a factor the better graphical modeling interface. [2]. The primary purpose of SEM rests in the adequacy of a predetermined theoretical model to explain relationships among observed variables and/or unobserved variables [3]. By far, the strongest argument in support of SEM is the need for researchers to explicitly state a priori causal theory. SEM has the availability of tests of 'Global Model Fit' and the ability to include multiple outcome variables [4]. The advantages of SEM also include the ability to model error terms and the ability to test coefficients across multiple groups [5].

System dynamics is an approach to understanding the behaviour of complex systems over time. It deals with internal feedback loops and time delays that affect the behaviour of the entire system [6, 7]. In another word, system dynamic is a methodology and mathematical modeling technique for framing, understanding, and discussing complex issues and problems [8]. System dynamics has been used extensively to aid in resource planning in the electric power industry. The many applications constitute a major body of work that has proven useful to large and small power companies as well as to government agencies at the local, state and federal level. The work has been performed by utility analysts, government planners, consultants and academics. System dynamics was first used in water resource planning in the study of river basin development. With that start, more research on system dynamic has been carried out [9, 10].

This project will use these two methods in an attempt to detect power quality events such as harmonics and voltage sags that occurred in electric power system. With all the steps in both methods, the data will be analyzed and thus, detecting the events and the possible mitigation will then be justified.

## **1.2 Problem Statement**

Poor power quality may cause electrical appliances malfunction or fuses to trip. When a disturbance occurs, huge financial losses may happen, with the consequent loss of productivity and competitiveness. This project was done to analyze, identify and classify the power quality events such as voltage sags and harmonics in electrical power system using structural equation modeling and system dynamic modeling because sometimes, it is hard to detect the events using the typical software used. So by using

these two methods, it might be a solution to easily detect the power quality events. From that, a comparison between structural equation modeling and system dynamic modeling will take position thus suggesting a possible mitigation for a better performance of electrical energy supply.

### **1.3 Objective of Project**

There are a few objectives for this project that includes:

1. To implement structural equation modeling and system dynamic method in electrical power system.
2. To determine several power quality events in electrical system using the methods mentioned.
3. To propose a possible mitigation for the power quality events occurred.

### **1.4 Scope of Project**

Every project has its scope and limitation. For this particular project, the scopes and limitation are:

1. This project only focused on two power quality events, which are voltage sags and harmonics.

2. The techniques use to identify the power quality events are only structural equation modeling and system dynamic.

Based on problem statement, objective and scope, the project was done step by step from the literature review and methodology until the final results and conclusion. The literature review, which contains the previous studies related to this project, is explained in next chapter.





## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

Electrical fault in a distribution network is almost impossible to avoid. Main causes for power quality disturbances may be due to insulation failure, tree falling, bird's contact, lightning or a fault on an adjacent feeder [11]. The research of power quality issues has captured ever increasing attention in the power engineering society [12]. A power quality problem can be described as any variation in the electrical power service, such as voltage sags and swells, interruptions, transients, harmonics, notches, and fluctuations, resulting in misoperation or failure of end-use equipment. To analyze these electric power system disturbances, data is often available as a form of a sampled time function that is represented by a time series of amplitudes [13].

According to Dogan Gokhan Ece and Omer Nezh Gerek [14], by using Joint 2-D-Wavelet Subspaces in detecting power quality events, good detection of power quality events than one-dimensional discrete wavelet transform is provided. This method also has more operational flexibility because of the available image processing tools. The test was applied on the voltage waveforms from real life power quality events captured at

20kHz from an experimental system, which is composed of a three-phase wye-connected 380V, 50Hz, 25kVA, 5-wire supply loaded with RL load banks and three-phase induction motors coupled with varying mechanical loads. The system also includes adjustable speed drives that control the induction motor. Another advantage is this method does not experience short discontinuity at the beginning and the end of the events. Although this method provides good detection of power quality events, it is difficult to observe the data if it is only processed in horizontal direction. This means that by using this method, the data have to be processed in both horizontal and vertical direction in order to easily observe the result.

Carlos A. Duque, Moises V. Ribeiro, Frederico R. Ramos and Jacques Szczupak [15] have published a journal in detecting power quality events based on the Divide and Conquer Principle and Innovation Concept. The power quality events detection is based on the Divide and Conquer Principle and Innovation Concept, as found in Kalman's filter formulation, and it is applied to voltage signals. This method makes use of digital signal processing techniques to obtain the stationary and non-stationary components of the monitored power quality events. The Innovation Concept is implemented to detect power quality disturbances start and end point. There are a few advantages of this method which are it introduces a simple and efficient way to evaluate the total harmonic distortion, in case of harmonic pollution, this method offers a new perspective in analyzing power quality events or even other problems in the power systems and by using this method, more accurate detections of power quality events can be accomplished. There is only one disadvantage of this method which is it requires a much reduced computational complexity for event detection, as compared to usual procedure. This means that this method cannot be used in a complex situation.

In analyzing power quality events, Dogan Gokhan Ece and Omer Nezh Gerek [16] used Higher Order Cumulants and Quadratic Classifiers method. This method uses higher order cumulants as the feature parameter and quadratic classifiers to classify the

power quality events. The events investigated are line-to-ground arcing faults and voltage sags due to the induction motor starting. A vector with six parameters is used as a feature vector. After the detection of power quality events, the maximum and minimum values of the cumulants around the event instant are used to classify the events. The conclusions made from the experiment done are higher order statistics are effective tools to detect deviations from Gaussianity, which is valid for several types of different loading conditions, the combination of higher order statistical parameters and quadratic classifiers is a promising tool for power quality event detection and classification and the cumulant calculation can be performed in real time even using simple microcontrollers even though for power quality event discrimination, using lower order cumulants is not possible as the complicated fluctuations cannot be visualized or differentiated [16].

Cheng-I Chen and Yu-Ting Fu [17] uses Wavelet and Adaptive Linear Combiner (ADALINE) to detect power quality events in 2010. By using this method, power system monitoring provides accurate and useful information to power grids and the starting and ending time of events can be effectively detected. On the conference paper, it was stated that power quality events are detected and classified by combining the wavelet analysis and adaptive linear combiner (ADALINE). The proposed algorithm is demonstrated by a simple laboratory setup with LabVIEW program and actual recorded waveforms. By using Wavelet and Adaptive Linear Combiner (ADALINE), time location of events can be detected more accurately than the traditional window-based methods and adaptive filtering techniques. But this method requires many computational operations and need data training and the adaptive approaches always suffer from numerical stability and computational burden.

Also, in the year 2010, Dr.M.Sushama, Dr.G.Tulasi Ram and Dr.A.Jaya Laxmi [18] used Wavelet Transforms in detecting power quality disturbances. Wavelet transform is used to identify the power quality disturbances at its instance of occurrence.

The power quality events considered are sag, swell, interruption, DC offset, frequency variation and harmonics. For this method, it is fast, sensitive and practical for detection and identification of power quality disturbances and it is suitable for stationary signal analysis where frequency component doesn't vary with time. The wavelet method can also be applied in other fields due to its variety of properties such as astronomy, nuclear engineering, acoustics, signal and image processing, speech discriminations, radar, human vision and in mathematics applications such as solving partial differential equations.

On every existing approach to compensate for voltage disturbances, the very first step is to detect the disturbance itself, and then other actions will come such as compensation or disconnection [19]. For this project, the power quality event was detected first using Power Analysis Software. After that, the analysis using Structural Equation Modeling and System Dynamic methods were done. The explanations on every method were discussed in Chapter 3.



## **CHAPTER 3**

### **METHODOLOGY**

#### **3.1 Introduction**

For the methodology of this project, it consists of five phases. The first phase is literature study of Structural Equation Modeling and System Dynamic methods. In this phase, the problem of Power Quality events is identified. The project will be followed by the second phase which is data collection. After the data is collected, the third phase of this project starts with the evaluation of the data using the first method as stated in the project title and also the flow chart given below. The methodology phase continues with the phase four which is the evaluation of the data using the second method and the last phase of this project is comparing the results of the two methods used, thus suggesting which one is the best method in detecting power quality events. Figure 3.1 below shows the flow chart of the project.

## **CHAPTER 4**

### **RESULT AND ANALYSIS**

This chapter discussed the result and analysis for this project. The analysis has been performed based on data obtained by the means of Structural Equation Modeling and System Dynamic method.

#### **4.1 Structural Equation Modeling**

Before SEM analysis was done, the data was converted to text file (\*.txt) and excel file (\*.xls) first. Figure 4.1 and 4.2 shows examples of the data in text and excel file.

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pmu skudai 22 kv (pmu skudai 22kv 07/28/00 11:39) Phase A voltage Harmonic

Harmonic	RMS value	Phase	% of Fundamental
0	17.264	180	0.13
1	13273.684	344.223	100
2	14.99	57.358	0.113
3	9.156	133.409	0.069
4	9.219	88.807	0.069
5	106.387	48.57	0.801
6	10.18	97.334	0.077
7	132.004	260.857	0.994
8	8.7	160.968	0.066
9	9.284	89.469	0.07
10	9.655	116.088	0.073
11	17.41	82.441	0.131
12	8.709	44.602	0.066
13	8.715	67.831	0.066
14	0	359.659	0
15	0	44.682	0
16	0	179.702	0

Ln 1, Col 1

Figure 4.1: Data in text file

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pmu skudai 22 kv (pmu skudai 22kv 07/28/00 11:39) Phase A voltage Harmonic

Harmonic	RMS value	Phase	% of Fundamental
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12	8.709	44.602	0.066
13	8.715	67.831	0.066
14	0	359.659	0
15	0	44.682	0
16	0	179.702	0
17	0	359.719	0
18	0	89.735	0
19	0	13.785	0
20	0	206.326	0
21	0	161.338	0
22	0	153.218	0
23	9.157	179.792	0.069
24	0	108.236	0

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Figure 4.2: Data in excel file

SEM analysis was done on voltage and current harmonic distortion. Analysis was performed on each phase which is Phase A, Phase B and Phase C. Usually, in SEM diagrams the variables are arranged from left to right. Observed variables are represented by rectangles and unobserved variables are represented by ellipses.

#### 4.1.1 Voltage harmonic distortion

##### 4.1.1.1 Phase A

Figure 4.3 shows the waveform of Phase A Voltage Harmonic Distortion analyzed from Power Analysis Software.

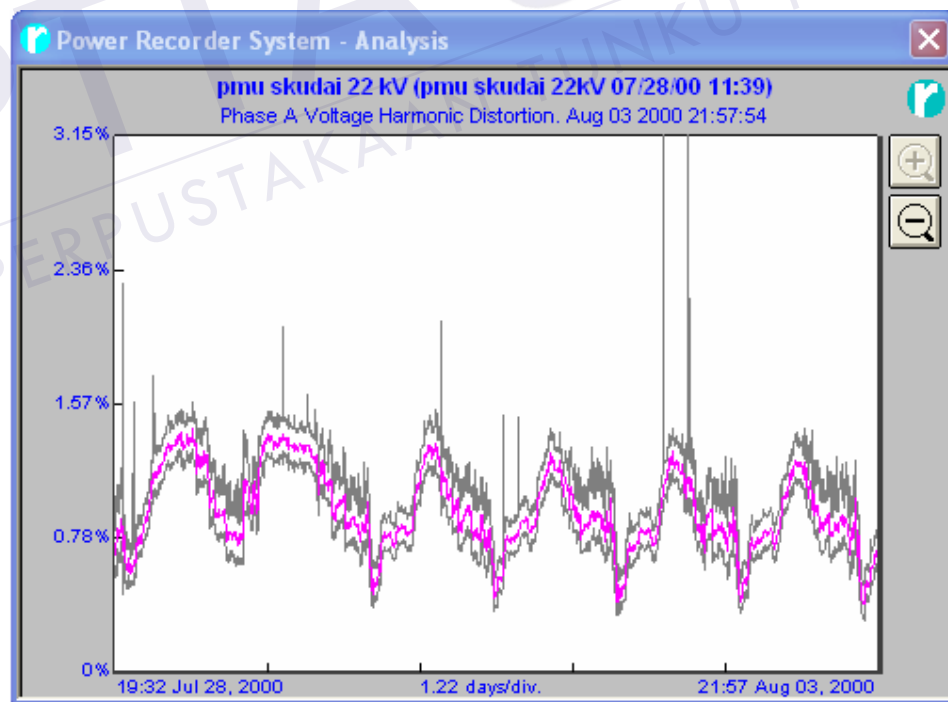


Figure 4.3: Waveform of Phase A Voltage Harmonic Distortion



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